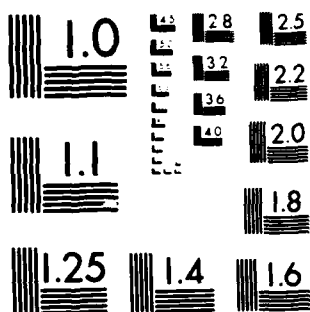


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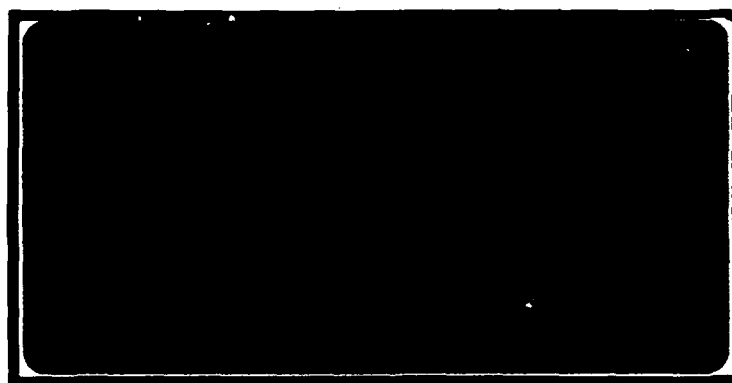
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displayed. Measured volumes are accurate ± 0.010 liters absolute and gas concentrations are reproducible to $\pm 0.01\%$ absolute. The system is technically simple and can be learned quickly by even relatively inexperienced operators.

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I. Introduction

Measurements of oxygen consumption, carbon dioxide production, and respiratory minute ventilation are routinely made in the physiology laboratory. In certain experimental situations it is desirable to make these respiratory measurements on a breath-by-breath basis and to have real-time display of the results. For most applications, however, the increased accuracy of batch methods which analyze the collected expired gas over several breaths outweighs the fast-response advantages of single-breath techniques. The hardware and software for a semi-automated system for collecting and analyzing such batch samples, performing calculations, and reporting of results is the subject of this report.

II. System and Techniques

To avoid the problems of calibration and drift of pneumotachometers, as well as the inherent inaccuracies of integrating flow signals to obtain volume, mixed expired gas is collected in a Douglas bag for a precisely timed interval. After removal of a small volume of gas for measurement of mixed expired oxygen and carbon dioxide concentrations (vide infra), the remaining contents of the bag are drawn into a 120-liter Tissot spirometer for a determination of volume. A rotary potentiometer and a 5 V regulated power supply convert the linear motion of the spirometer bell into a electrical signal. The voltage output is read on a digital voltmeter (DVM) with a resolution of 1 mV. This arrangement makes possible volume measurements with a resolution of ± 10 ml (see Appendix 1). The temperature of the gas is measured with a precision linearized thermistor mounted in the top of the spirometer bell. Tissot DVM voltages before and after introduction of the mixed expired gas sample, Tissot temperature, duration of the expired gas collection, and the barometric pressure are entered manually into a Hewlett-Packard (HP) 9825 desktop computer.

Before the mixed expired gas collected in the Douglas bag is evacuated into the Tissot spirometer, a small portion (usually 100 to 500 ml) is removed with a gas-tight syringe after several flushes between syringe and bag to insure a representative sample. Oxygen and carbon dioxide concentrations are determined by injecting this gas into the appropriate analyzer(s). Any analyzer with an analog voltage output that is linear with concentration can be used. Excellent results have been obtained with the fast-response Applied Electrochemistry instruments (model S3-A for O_2 , model CD-3A for CO_2). These units are quite stable and exhibit very good reproducibility. The computer system gives the operator the option either to inject the sample into separate instruments and read each instrument consecutively or to use a single multiple-gas instrument, or two single gas analyzers in series, to measure O_2 and CO_2 concentrations simultaneously. Water vapor is removed by passing the gas sample through a dessicant chamber prior to injecting it into the instrument(s).

The HP 9825 desktop computer, an associated HP 3495A scanner, and an HP 3455A DVM are used to read and record automatically the outputs of the gas analyzers. To increase the accuracy of these determinations by reducing the instrument noise effects, the analog signals are digitized at a sample rate of ~20/sec for a period of 10 sec. A mean is computed for both the O_2 and CO_2 signals and these values are used in all calculations. This digital filtering permits repeatability of a given reading to $\pm 0.01\%$ absolute without decrement to the response time of the analyzers. The program requires the output of the oxygen analyzer to be connected to channel 1 of the HP 3495A scanner and that of the carbon dioxide analyzer to channel 2.

The analyzers themselves are calibrated prior to each experiment. This is done as follows. A standard gas with concentrations of O_2 and CO_2 near the low

end of the range of interest is analyzed by the instruments. The outputs signals and the known values are stored in the computer. The procedure is repeated for a gas with concentrations at the high end of expected values. The program uses these calibration values to determine the concentration of an unknown sample:

$$U_i = [(C_{Hi} - C_{Li}) / (V_{Hi} - V_{Li})] \cdot (V_{Ui} - V_{Li})$$

where

U_i = concentration of gas (i) in the sample

C_{Hi} = concentration of gas (i) in high calibration mixture

C_{Li} = concentration of gas (i) in low calibration mixture

V_{Hi} = output voltage of analyzer for high calibration mixture

V_{Li} = output voltage of analyzer for low calibration mixture

V_{Ui} = output voltage of analyzer for gas (i) in unknown sample.

The computer also prompts the operator during the course of an experiment via its alphanumeric LED display. The operator interacts with the program by using the built-in keyboard. The software automatically computes the calibration curve for each analyzer, times the data acquisition, calculates the gas concentrations and other respiratory parameters, and prints these results.

The respiratory parameters are calculated from the equations given by Otis

(1) as follows:

$$V_{E \text{ ATPS}} = (V_f - V_i) \cdot (K) + s$$

$$\dot{V}_{E \text{ ATPS}} = V_{E \text{ ATPS}} / t$$

$$*P_{H_2O} = \exp [18.306 - 3816.44 / (T + 273 - 46.13)] + 0.4$$

$$\dot{V}_{E \text{ BTPS}} = (\dot{V}_{E \text{ ATPS}}) [310 / (273 + T)] [(P_B - P_{H_2O}) / (P_B - 47)]$$

$$\dot{V}_{E \text{ STPD}} = (\dot{V}_{E \text{ BTPS}}) (273 / 310) [(P_B - 47) / 760]$$

$$\dot{V}_{CO_2} = (\dot{V}_{E \text{ STPD}}) \cdot F_{ECO_2}$$

$$R = (F_{\text{ECO}_2})(1 - F_{\text{IO}_2}) / [(1 - F_{\text{ECO}_2}) \cdot F_{\text{FIO}_2} - F_{\text{EO}_2}]$$

$$\dot{V}_{\text{O}_2} = \dot{V}_{\text{CO}_2} / R$$

where:

F_{EO_2} = fractional concentration of O_2 in expired gas

F_{ECO_2} = fractional concentration of CO_2 in expired gas

F_{IO_2} = fractional concentration of oxygen in inspired gas

V_f = final voltage output of spirometer potentiometer (V)

V_i = initial voltage output of spirometer (V)

K = calibration constant of spirometer (ℓ/V) (See Appendix 1)

s = volume of sample withdrawn from Douglas bag for analysis (ℓ)

t = time interval over which expired volume was collected (min)

$P_{\text{H}_2\text{O}}$ = water vapor pressure in spirometer (mm Hg)

T = spirometer temperature ($^{\circ}\text{C}$)

P_B = barometric pressure (mm Hg)

47 = water vapor pressure (mm Hg) of expired gas (assumed body temperature of 37°C)

$V_{\text{E ATPS}}$ = volume of gas collected in spirometer (ℓ), ambient temperature, pressure, saturated with water vapor

$\dot{V}_{\text{E ATPS}}$ = minute volume of gas collected in spirometer (ℓ/min)

$\dot{V}_{\text{E BTPS}}$ = expired minute volume (ℓ/min), body temperature, pressure, saturated with water

$\dot{V}_{\text{E STPD}}$ = expired minute volume (ℓ/min), standard temperature, pressure, dry

\dot{V}_{CO_2} = CO_2 production rate (ℓ/min)

R = respiratory quotient, $\dot{V}_{\text{CO}_2} / \dot{V}_{\text{O}_2}$

\dot{V}_{O_2} = O_2 consumption rate (ℓ/min)

It should be noted that these equations assume the inspired carbon dioxide concentration is zero. However, they do permit the subject to be at variable ambient pressures and also allow the inspired oxygen concentration to be varied.

III. Computer Programs

A. Introduction

Program "GAS1," described in the next section, is used for the situation in which a sample is put into the O_2 analyzer, its concentration determined, then a separate sample is pushed into the CO_2 instrument, and its concentration measured. If the equipment is arranged such that a gas sample is fed simultaneously into both gas analyzers, program "GAS2" should be used. Data in the form of meter readings recorded manually can be analyzed with program "manGAS." Each of the programs compute the following parameters:

\dot{V}_E BTPS = expiratory minute volume (l/min) at body temperature ($37^\circ C$),
body ambient pressure (chamber pressure), saturated with water
vapor.

\dot{V}_E STPD = expiratory minute volume (l/min) referred to standard
conditions (i.e., $0^\circ C$, 760 mm Hg ambient pressure, dry gas)

R = respiratory quotient, $\dot{V}_{CO_2} / \dot{V}_{O_2}$

\dot{V}_{O_2} = oxygen consumption rate (l/min STPD)

\dot{V}_{CO_2} = carbon dioxide production rate (l/min STPD)

Program listings and a variable allocation list are given in the appendices.

B. "GAS1"

This program is used when oxygen and carbon dioxide concentrations are determined sequentially.

1. Insert program tape
Press: LOAD
Type: 1
Press: EXECUTE
2. When end of line mark (␣) is displayed
Press: RUN
3. When "Insert tape cartridge" is displayed;
 - a. Check that program tape is inserted
 - b. Press: CONTINUE
4. When "Remove tape cassette" is displayed;
 - a. Remove tape
 - b. Press: CONTINUE
5. When "Printer Select Code = ?" is displayed;
 - a. Type: number of external printer select code
 - b. Press: CONTINUE
6. When "O₂ → Ch.1 ** CO₂ → Ch.2 CHECK HOOKUP!" is displayed;
 - a. Verify that O₂ analyzer is connected to channel 1 of scanner, CO₂ to channel 2
 - b. Press: CONTINUE
7. When "Surface Barometric press (mm Hg)?" is displayed;
 - a. Type: number (in millimeters of mercury)
 - b. Press: CONTINUE
8. When "Chamber Gauge Pressure (fsw) = ?" is displayed;
 - a. Type: number (for ambient pressure at subject in feet of seawater)
 - b. Press: CONTINUE
9. When "Spirometer cal. constant (liters/volt) = ?" is displayed;
 - a. Type: number for system being used
 - b. Press: CONTINUE
10. When "Syringe sample vol., liters?" is displayed;
 - a. Type: number (for volume of sample removed from bag for gas analyzers)
 - b. Press: CONTINUE
11. When "Subject Name?" is displayed;
 - a. Type: name (max. of 80 characters)
 - b. Press: CONTINUE
 - c. Name is printed
12. When "Date?" is displayed;
 - a. Type: date (max. of 20 characters)

- b. Press: CONTINUE
 - c. Date is printed
13. When "Enter Comment" is displayed;
- a. Type: comment (max. of 80 characters)
 - b. Press: CONTINUE
 - c. Comment is printed
14. When "O₂ high cal. percent = " is displayed;
- a. Type: percent concentration of O₂ in high calibration mixture
 - b. Press: CONTINUE
15. When "CO₂ high cal. percent = " is displayed;
- a. Type: percent concentration of CO₂ in high calibration mixture
 - b. Press: CONTINUE
16. When "Press CONT to read O₂" is displayed;
- a. Flow high calibration gas into oxygen analyzer
 - b. When instrument reading is stable,
Press: CONTINUE
 - c. Computer reads instrument output for 10 sec.
17. When "Repeat Reading?" is displayed;
- a. If yes,
 - 1) Press: YES (special function key f₀)
 - 2) Go to step 16
 - b. If no,
 - 1) Press: NO (special function key f₆)
 - 2) Go to step 18
18. When "Press CONT to read CO₂" is displayed;
- a. Flow high calibration gas into carbon dioxide analyzer.
 - b. When instrument reading is stable,
Press: CONTINUE
 - c. Computer reads instrument output for 10 sec.
19. When "Repeat Reading?" is displayed;
- a. If yes,
 - 1) Press: YES
 - 2) Go to step 18
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 20
20. [The high calibration gas O₂ and CO₂ concentrations and the analyzer output voltages are printed.]
21. When "Repeat high gas calibration?" is displayed inspect the values printed in step 19.
- a. If the results are acceptable,
 - 1) Press: NO
 - 2) Go to step 22
 - b. If the high gas calibration must be repeated;

- 1) Press: YES
 - 2) Go to step 14
22. When "O₂ low cal. percent = ?" is displayed;
- a. Type: percent concentration of O₂ in low calibration mixture
 - b. Press: CONTINUE
23. When "CO₂ low cal. percent = ?" is displayed;
- a. Type: percent concentration of CO₂ in low calibration mixture
 - b. Press: CONTINUE
24. When "Press CONT to read O₂" is displayed;
- a. Flow low calibration gas into O₂ analyzer
 - b. When instrument reading is stable,
Press: CONTINUE
 - c. Computer reads analyzer output for 10 sec
25. When "Repeat Reading?" is displayed;
- a. If yes,
 - 1) Press: YES
 - 2) Go to step 24
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 26
26. When "Press CONT to read CO₂" is displayed;
- a. Flow low calibration gas into CO₂ analyzer
 - b. When instrument reading is stable
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
27. When "Repeat Reading?" is displayed;
- a. If yes,
 - 1) Press: YES
 - 2) Go to step 26
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 28
28. [The low calibration gas O₂ and CO₂ concentrations and the analyzer output voltages are printed.]
29. When "Repeat low gas calibration?" is displayed, inspect the values printed in step 27.
- a. If the results are acceptable,
 - 1) Press: NO
 - 2) Go to step 30
 - b. If the low gas calibration must be repeated,
 - 1) Press: YES
 - 2) Go to step 22
30. When "Measure inspired O₂?" is displayed;
- a. If you want to measure the O₂ concentration in a sample of inspired gas,
 - 1) Press: YES

- 2) Go to step 31
- b. If you want to assume an inspired gas concentration of 20.95%,
 - 1) Press: NO
 - 2) Go to step 33
- 31. When "Press CONT to read inspired O₂" is displayed;
 - a. Flow inspired gas sample into O₂ analyzer
 - b. When instrument reading is stable,
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
 - d. Inspired O₂ percent is printed
- 32. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 31
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 33
- 33. When "Press CONT to start clock" is displayed;
 - a. When ready to start experiment
Press: CONTINUE
 - b. Computer internal elapsed time clock starts
- 34. When "Press CONT to read O₂" is displayed;
 - a. Flow expired gas sample into O₂ analyzer
 - b. When reading is stable
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
- 35. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 34
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 36
- 36. When "Press CONT to read CO₂" is displayed;
 - a. Flow expired gas sample into CO₂ analyzer
 - b. When reading is stable
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
- 37. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 36
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 38
- 38. [Analyzer output voltages are printed.]

39. When "Enter Comment" is displayed;
 - a. Type: comment (80 characters max.)
 - b. Press: CONTINUE
 - c. Comment is printed
40. When "Spirometer initial reading, Volts" is displayed;
 - a. Type: initial reading on DVM connected to rotary potentiometer of spirometer (value should be accurate to nearest 0.001 V)
 - b. Press: CONTINUE
41. When "Spirometer final reading, Volts" is displayed;
 - a. Type: final spirometer DVM reading when Douglas bag has been emptied into it.
 - b. Press: CONTINUE
42. When "Time duration of sample collection, min." is displayed;
 - a. Type: time
 - b. Press: CONTINUE
43. When "Spirometer temp. in deg. C" is displayed;
 - a. Type: reading from thermometer mounted in spirometer bell
 - b. Press: CONTINUE
44. [Values are printed.]
45. When "Change data?" is displayed, inspect numbers printed in step 44;
 - a. If they are correct,
 - 1) Press: NO
 - 2) Go to step 47
 - b. If they must be changed,
 - 1) Press: YES
 - 2) Go to step 46
46. ["** CORRECTED DATA **" is printed.] Go to step 40.
47. [Computed values of \dot{V}_E (BTPS), \dot{V}_E (STPD), R, \dot{V}_{O_2} , \dot{V}_{CO_2} are printed.]
48. When computer displays "RECAL -- Press f1 to continue" and beeps once each second,
Press: special function key f_1
49. When "Do you want to recal. O2 & CO2?" is displayed;
 - a. If no,
 - 1) Press: NO
 - 2) Go to step 34
 - b. If yes,
 - 1) Press: YES
 - 2) Go to step 50
50. When "Press CONT to recal. high O2" is displayed;
 - a. Flow high calibration gas into O_2 analyzer
 - b. When reading is stable
Press: CONTINUE

- c. Computer reads analyzer output voltage for 10 sec
- 51. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 50
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 52
- 52. When "Press CONT to recal. high CO₂" is displayed;
 - a. Flow high calibration gas into CO₂ analyzer
 - b. When reading is stable,
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
- 53. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 52
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 54
- 54. [Analyzer output voltages are printed.]
- 55. When "Press CONT to recal. low O₂" is displayed;
 - a. Flow low calibration gas into O₂ analyzer
 - b. When reading is stable
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
- 56. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 55
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 57
- 57. When "Press CONT to recal low CO₂" is displayed;
 - a. Flow low calibration gas into CO₂ analyzer
 - b. When reading is stable
Press: CONTINUE
 - c. Computer reads analyzer output voltage for 10 sec
- 58. When "Repeat Reading?" is displayed;
 - a. If yes,
 - 1) Press: YES
 - 2) Go to step 57
 - b. If no,
 - 1) Press: NO
 - 2) Go to step 59

59. [Analyzer output voltages are printed.]
Go to step 34 (To stop program, Press: STOP).

C. "GAS2"

This program is used when the O_2 and CO_2 analyzers are connected in series so that a gas sample can be flowed through both simultaneously. Detailed user instructions will not be given since the program is very similar in operation to "GAS1." The major differences are the following:

1. The inspired O_2 concentration is entered by hand instead of being measured by the computer directly.
2. The high and low calibration gases are measured by both analyzers at the same time.
3. Two separate determinations of concentration are made for each sample of gas. Both values are printed, but the computer takes the mean for use in the computation of respiratory parameters.

A program listing is given in Appendix 2.

To load the program, proceed as follows:

1. Insert program tape
Press: LOAD
Type: 2
Press: EXECUTE
2. When end of line mark (␣) is displayed
Press: RUN
3. Follow the operator prompts on the display throughout the program.

D. "manGAS"

This program is used when experimental data have been recorded manually. It allows values to be entered into the computer via its keyboard; the results are printed in the same format as for the two previously described automatic data acquisition programs. The operator prompts are similar enough to those for "GAS1" that they will not be detailed here. The major differences between "manGAS" and "GAS1" are as follows:

1. The body temperature is entered by the user and is not assumed to be 37°C.
2. The expired gas water vapor pressure is not assumed to be 47 mm Hg but is calculated from the body temperature entered.

A program listing is given in Appendix 3.

To load the program into the computer:

1. Insert program tape
Press: LOAD
Type: 3
Press: EXECUTE
2. When end of line mark (␣) is displayed
Press: RUN
3. Follow the operator prompts on the display throughout the program.

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1. Otis, A.B. Quantitative Relationship in Steady-State Gas Exchange. Fenn, W.O., Rahn, H. eds. Handbook of Physiology, Section 3: Respiration Volume 1. Washington, D.C.: American Physiological Society; 1964:681-698.
2. Reid, R.C.; Prausnitz, J.M.; Sherwood, T.K. The properties of gases and liquids. 3rd ed. New York, NY: McGraw-Hill; 1977.
3. Handbook of Chemistry and Physics. Chemical Rubber Co., Cleveland, 1965.

Appendix 1

Calibration of Tissot Spirometer

The Tissot spirometer used has a rotary potentiometer attached to its pulley. This potentiometer, used in conjunction with a regulated voltage source, makes possible a much greater accuracy than the standard pointer-on-a-meter-stick method. The spirometer system is calibrated in the following way. The bell is raised to its maximum height. The pulley is rotated and allowed to move relative to the chain attached to the bell until the digital voltmeter that monitors the potentiometer voltage reads a value approximately equal to the output of the regulated supply itself. The system is allowed to equilibrate in this position at least 12 h. The gas in the spirometer is then removed in 100 ml increments with a calibrated gas syringe. The signal from the potentiometer is recorded after each decrement in volume. Once all the gas is removed, a linear regression is performed on the data with volume decrement (liters) as the ordinate and the corresponding voltage change (volts) as the abscissa. The slope of the line thus determined is the calibration constant for the spirometer in liters/volt. At the time of calibration the supply voltage, V_0 , is accurately measured. If for any reason this value changes, a new spirometer constant can be calculated without repeating the lengthy calibration procedure:

$$K = K_0 (V/V_0)$$

where:

K = new constant(l/V)

K_0 = original constant(l/V)

V = new output voltage of supply (V)

V_0 = original output voltage of supply (V).

It should be noted that the spirometer must be calibrated by removing gas if an accurate constant is to be found. If, instead, room air is put into the spirometer, the humidification and temperature equilibration processes cause the volume to fluctuate after each incremental volume is added. This increases the scatter of the data and significantly enlarges the error in the final determination of the calibration constant.

"GAS1"

Equipment List for Computer System

1. Hewlett-Packard (HP) 9825B computer
 or
 HP 9825A computer with following ROM's:
 - a. general I/O
 - b. extended I/O
 - c. advanced programming
 - d. string variable
2. HP 98035A real-time clock
3. HP 3495A scanner
4. HP 3455A digital voltmeter
5. HP 9866, HP 9876 or other suitable external printer
6. HP 98034A (HP-IB) interface bus

"GAS1"

Program Listing

```

0: "This program is called GAS1. It reads both O2 & CO2 gas analyzers":
1: "and calculates gas consumption and production. It provides both high":
2: "and low gas calibrations and recalibrations during a run. The O2 &":
3: "CO2 instruments are read at separate times in this program.":
4: "Version: 16 March 1982 ** RPL ":
5:
6: dim BS[80],CS[20],DS[80],ES[80]
7: dim O[2],Z[2],Y[6],S[2],V[2],A$[29],C[2],U[2],I[2]
8: dsp "Insert tape cartridge";beep;stp
9: ldk 0
10: rew
11: dsp "Remove tape cassette";stp
12: wrt 9,"A1";wrt 9,"U1010000/"
13: wrt 9,"U2=12";wrt 9,"U2C"
14: ent "Printer Select Code=?",C
15: if C=706;wtb 706,27,40,65
16: cli 7;rem 7;rem 709;clr 722;clr 709
17: wrt 722,"FLR3T2:13A0H0D1"
18: char(195)+A$[1]
19: char(200)+A$[2]
20: char(197)+A$[3]
21: char(195)+A$[4]
22: char(203)+A$[5]
23: char(160)+A$[6]
24: char(200)+A$[7]
25: char(207)+A$[8];char(207)+A$[9];char(203)+A$[10]
26: char(213)+A$[11];char(208)+A$[12];char(161)+A$[13]
27: dsp "O2+Ch.1*CO2+Cn.2",A$;stp
28: ent "Surface Barometric press(mm Hg)?",I[1]
29: ent "Chamber Gauge Pressure (fsw)=?",V
30: V*760/33.07+I[1]+I[2]
31: ent "Spirometer cal. constant (1/V)=?",X
32: ent "Syringe sample vol., liters?",H

```

```

33: ent "Subject Name?",B$
34: fmt ;wrt C,"Subject name: ",B$
35: ent "Date?",C$
36: wrt C,"Date: ",C$
37: ent "Enter Comment",E$
38: wrt C;wrt C,E$;wrt C
39: fmt 6,78"*/;C+.6+L;wrt L
40: ent "O2 high cal. percent=",U[1]
41: ent "CO2 high cal. percent=?",U[2]
42: dsp "Press CONT to read O2";stp
43: 1+N;cll 'SCAN'
44: Z[1]+S[1]
45: ent "Repeat Reading?",Q
46: if Q=1;0+Q;gto -4
47: dsp "Press CONT to read CO2";stp
48: 2+N;cll 'SCAN'
49: Z[2]+S[2]
50: ent "Repeat Reading?",Q
51: if Q=1;0+Q;gto -4
52: fmt 9,f6.3,z;fmt ;wrt C
53: fmt 8,f8.5,z;C+.8+S;C+.9+U
54: wrt U,"O2 high cal. conc.= ",U[1],"%";U[1]/100+U[1]
55: wrt S,"O2 high cal. read.= ",S[1]," volts"
56: wrt U,"CO2 high cal. conc.= ",U[2],"%";U[2]/100+U[2]
57: wrt S,"CO2 high cal. read.= ",S[2]," volts"
58: fmt ,2/;wrt C;fmt
59: ent "Repeat high gas calibration?",Q
60: if Q=1;0+Q;gto 40
61: ent "O2 low cal. percent=?",r1
62: ent "CO2 low cal. percent=?",r2
63: dsp "Press CONT to read O2";stp
64: 1+N;cll 'SCAN'
65: Z[1]+O[1]
66: ent "Repeat Reading?",Q
67: if Q=1;0+Q;gto -4
68: dsp "Press CONT to read CO2";stp

```

```

69: 2+N;cll 'SCAN'
70: Z[2]+O[2]
71: ent "Repeat Reading?",Q
72: if Q=1;0+Q;gto -4
73: fmt ;wrt C
74: wrt U,"O2 low cal. conc.= ",r1,"%";r1/100+r1
75: wrt S,"O2 low cal. read.= ",O[1]," volts"
76: wrt U,"CO2 low cal. conc.= ",r2,"%";r2/100+r2
77: wrt S,"CO2 low cal. read.= ",O[2]," volts"
78: fmt ,2/wrt C;fmt
79: ent "Repeat low gas calibration?",Q
80: if Q=1;0+Q;gto 61
81: .2095+r5
82: ent "Measure inspired O2?",Q
83: if Q=1;0+Q;gto 85
84: gto 94
85: dsp "Press CONT to read inspired O2";stp
86: 1+N;cll 'SCAN'
87: Z[1]+r5
88: (U[1]-r1)/(S[1]-O[1])*(r5-O[1])+r1+r5
89: 100r5+r5
90: dsp "Inspired O2 %=" ,r5;stp
91: r5/100+r5
92: ent "Repeat Reading?",Q
93: if Q=1;0+Q;gto 85
94: dsp "Press CONT to start clock";stp
95: wrt 9,"U2G/";0+r3
96: fmt ,/,78"-";wrt C;fmt
97: dsp "Press CONT to read O2 ";stp
98: 1+N;cll 'SCAN'
99: Z[1]+C[1]
100: ent "Repeat Reading?",Q
101: if Q=1;0+Q;gto -4
102: dsp "Press CONT to read CO2";stp
103: 2+N;cll 'SCAN'
104: Z[2]+C[2]

```

```

105: ent "Repeat Reading?",Q
106: if Q=1;0→Q;goto -4
107: fmt , "Gas Reading: O2:",r7.3," CO2: ",f8.5," Volts"
108: wrt C,C[1],C[2];fmt
109: beep;fmt ,/,c13,r2.0;wrt C,"Rest period #","r3
110: ent "Enter Comment",D$;fmt
111: wrt C,D$;wrt C
112: ent "Spirometer initial reading,Volts",A
113: ent "Spirometer final reading,Volts",B
114: ent "Time duration of collection,min.",T
115: ent "Spirometer temp. in deg. C",D
116: fmt 4,f7.3,z;C+.4→L
117: wrt L,"Surface Barometric Pressure=",I[1]," mm Hg"
118: wrt L,"Chamber Gauge Pressure= ",V," tsw"
119: wrt L,"Spirometer calibration constant= ",X," liters/volt"
120: wrt L,"Syringe volume=",H," liters"
121: 100r5→r7;wrt L,"Inspired O2 conc.= ",r7,"%"
122: wrt L,"Spirometer initial reading=",A," Volts"
123: wrt L,"Spirometer final reading=",B," Volts"
124: wrt L,"Time duration of sample collection=",f," min."
125: wrt L,"Spirometer temperature=",D," deg. C"
126: ent "Change data?",H
127: if Q=1;0→Q;wrt C,"**CORRECTED DATA**";goto 112
128: exp(18.3036-3816.44/(D+273-46.13))+.4→E
129: (U[1]-r1)/(S[1]-O[1])*(C[1]-O[1])+r1→G
130: (U[2]-r2)/(S[2]-O[2])*(C[2]-O[2])+r2→F
131: (B-A)*X+H→Y[1]
132: Y[1]/T→Y[2]
133: Y[2]*(310/(273+D))*(I[2]-E)/(I[2]-47)→Y[3]
134: Y[3]*(273/310)*(I[2]-47/760)→Y[4]
135: Y[4]*F→Y[5]
136: F*(1-r5)/((1-F)*r5-G)→R
137: Y[5]/R→Y[6]
138: fmt 5,/,f7.4,10x,f7.4;C+.5→L;wrt L,"FE O2=",G,"FE CO2= ",F
139: fmt 5,2/,c7,4x,c7,6x,c1,9x,c3,9x,c4,6x,c4
140: wrt L,"VE BTP", "VE STD", "R", "VO2", "VCO2", "TIME"

```

[illegible]

```

177: if Q=1;0→Q;gto -4
178: wrt C
179: wrt S,"New O2 low cal. read. = ",O[1]," volts"
180: wrt S,"New CO2 low cal. read. = ",O[2]," volts"
181: wrt L;wrt L;fmt ;wrt C;beep;beep
182: fmt ,78"*",/,78"*",/;wrt C
183: fmt ;gto 97
184:
185: "SCAN":
186: 0→J;0→Z[1];0→Z[2];0→P
187: eir 9
188: oni 9,"TIME"
189: dsp "Taking DVM readings"
190: wrt 9,"ULG/"
191: fmt 1,f3.0
192: wrt 709.1,N;trg 722;red 722,V[N];J+1→J
193: V[N]+Z[N]→Z[N]
194: if P=1;jmp 2
195: gto 192
196: wrt 9,"U2V";red 9,K;K/60000→K
197: Z[N]/J+Z[N];dsp
198: beep;wait 200;beep
199: ret
200:
201: "TIME":
202: 1→P
203: iret

```

"GAS1"

Variable Assignments

A	initial spirometer volts
B	final spirometer volts
C	printer select code
D	spirometer temperature ($^{\circ}\text{C}$)
E	water vapor pressure in spirometer (mm Hg)
F	expired gas CO_2 concentration
G	expired gas O_2 concentration
H	sample syringe volume (l)
J	counter for number of DVM readings taken
K	elapsed time
L	printer select code + format number
N	used
P	used
Q	yes/no flag
R	respiratory quotient
S	used
T	time duration of gas collection (min)
U	used
V	chamber gauge pressure (fsw)
X	spirometer calibration constant (l/V)

I[*]: ambient pressure
 I[1] surface barometric pressure (mm Hg)
 I[2] ambient pressure in chamber (mm Hg)

O[*]: low calibration analyzer output voltages
 O[1] O₂
 O[2] CO₂

S[*]: high calibration analyzer output voltages
 S[1] O₂
 S[2] CO₂

U[*]: high calibration gas concentrations
 U[1] O₂
 U[2] CO₂

V[*]: temporary storage of DVM reading

Y[*]: calculated values
 Y[1] volume of gas collected in spirometer
 Y[2] minute volume of gas in spirometer
 Y[3] minute volume BTPS
 Y[4] minute volume STPD
 Y[5] \dot{V}_{CO_2}
 Y[6] \dot{V}_{O_2}

Z[*]: temporary storage of averaged DVM readings

A\$ used
 B\$ subject name
 C\$ date
 D\$ comment for whole experiment
 E\$ comment for each gas analysis

r1 low calibration O₂ concentration
 r2 low calibration CO₂ concentration
 r3 test period number
 r5 inspired O₂ concentration (decimal)
 r7 inspired O₂ concentration (%)

"GAS1"

Special Function Keys

f_0	/1 → Q
f_1	*1 → r14
f_6	/0 → Q

"GAS2"

Program Listing

```

0: "This program is called GAS2. It reads both O2 & CO2 gas analyzers":
1: "and calculates gas consumption and production. It provides both high":
2: "and low gas calibrations and recalibrations during a run. The O2 &":
3: "CO2 instruments are read simultaneously in this program.":
4: "Version: 16 March 1982 ** RPL ":
5:
6: dim B$(80),C$(20),D$(80),E$(80)
7: dim O(2),Z(2),Y(6),S(2),X(2),V(2),A$(29),C(2),N(2,2),U(2),I(2)
8: dsp "Insert tape cartridge";beep;stp
9: ldk 0
10: rew
11: dsp "Remove Program Tape";stp
12: wrt 9,"A1";wrt 9,"U1D10000/"
13: wrt 9,"U2=12";wrt 9,"U2C"
14: wtb 706,27,40,65
15: cli 7;rem 7;rem 709;clr 722;clr 709
16: wrt 722,"FLR3T2M13A0H0D1"
17: char(195)+A$(1)
18: char(200)+A$(2)
19: char(197)+A$(3)
20: char(195)+A$(4)
21: char(203)+A$(5)
22: char(160)+A$(6)
23: char(200)+A$(7)
24: char(207)+A$(8);char(207)+A$(9);char(203)+A$(10)
25: char(213)+A$(11);char(209)+A$(12);char(161)+A$(13)
26: dsp "O2+Ch.1+CO2+Ch.2",A$;stp
27: ent "Printer Select Code?";C
28: ent "Surface Barometric Press (mm Hg)?",I(1)
29: ent "Chamber Gauge Pressure (PSW)=?",V
30: V*760/33.07+I(1)+I(2)
31: ent "Spirometer cal. constant (1/V)=?",X
32: ent "Syringe sample vol., liters?",li

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```

33: ent "Inspired O2 percent=?",r5;r5/100+r5
34: ent "Subject Name?",B$
35: fmt ;wrt C,"Subject name: ",B$
36: ent "Date?",C$
37: wrt C,"Date: ",C$
38: ent "Enter Comment",E$
39: wrt C;wrt C,E$;wrt C
40: fmt 6,78" ",/;C+.6+L;wrt L
41: ent "O2 high cal. percent=",U[1]
42: ent "CO2 high cal. percent=?",U[2]
43: dsp "Press CONT to take reading";stp
44: cll 'SCAN'
45: Z[1]+S[1];Z[2]+S[2];beep;fmt 9,f6.3,z;fmt ;wrt C
46: fmt 8,f6.3,z;C+.8+S;C+.9+U
47: wrt U,"O2 high cal. conc.=",U[1],"%";U[1]/100+U[1]
48: wrt S,"O2 high cal. read.=",S[1],"volts"
49: wrt U,"CO2 high cal. conc.=",U[2],"%";U[2]/100+U[2]
50: wrt S,"CO2 high cal. read.=",S[2],"volts"
51: ent "Repeat Reading?",Q
52: if Q=1;0+Q;goto 41
53: ent "O2 low cal. percent=?",r1
54: ent "CO2 low cal. percent=?",r2
55: dsp "Press CONT to take reading";stp
56: cll 'SCAN'
57: Z[1]+O[1];Z[2]+O[2];beep;fmt ;wrt C
58: wrt U,"O2 low cal. conc.=",r1,"%";r1/100+r1
59: wrt S,"O2 low cal. read.=",O[1],"volts"
60: wrt U,"CO2 low cal. conc.=",r2,"%";r2/100+r2
61: wrt S,"CO2 low cal. read.=",O[2],"volts"
62: ent "Repeat Reading?",Q
63: if Q=1;0+Q;goto 53
64: dsp "Press CONT to start clock";stp
65: wrt 9,"U2G/";0+r3
66: fmt /,78" ";wrt C;fmt
67: dsp "Press CONT to read O2 & CO2";stp
68: cll 'SCAN'

```

```

69: z[1]←N[1,1];z[2]←N[1,2]
70: dsp "press CONT to take 2nd reading";beep;stp
71: cll "SCAN"
72: z[1]←N[2,1];z[2]←N[2,2];beep;r3←1+r3
73: fmt , "1st Reading  O2:",f9.3," CO2: ",f9.3
74: wrt C,N[1,1],N[1,2]
75: fmt , "2nd Reading  O2:",f9.3," CO2: ",f9.3
76: wrt C,N[2,1],N[2,2]
77: (N[1,1]+N[2,1])/2←C[1];(N[1,2]+N[2,2])/2←C[2]
78: fmt , "Avg Reading  O2:",f9.3," CO2: ",f9.3
79: wrt C,C[1],C[2];fmt
80: beep;fmt ,/,cl3,f2.0;wrt C,"Test Period #",r3
81: ent "Enter Comment",D$;fmt
82: wrt C,D$;wrt C
83: ent "Spirometer initial reading,volts",A
84: ent "Spirometer final reading,volts",B
85: ent "Time duration of collection,min.",F
86: ent "Spirometer temp. in deg. C",D
87: fmt 4,f7.3,z;C+.4←L
88: wrt L,"Surface Barometric Pressure=",I[1]," mm Hg"
89: wrt L,"Chamber Gauge Pressure= ",V," fsw"
90: wrt L,"Spirometer calibration constant= ",X," liters/volt"
91: wrt L,"Syringe volume=",B," liters"
92: 100r5←r7;wrt L,"Inspired O2 conc.= ",r7,"%"
93: wrt L,"Spirometer initial reading=",A," volts"
94: wrt L,"Spirometer final reading=",B," volts"
95: wrt L,"Time duration of sample collection=",F," min."
96: wrt L,"Spirometer temperature=",D," deg. C"
97: ent "Change data?",V
98: if Q=1;0→Q;wrt C,"**CORRECTED DATA**";goto 83
99: exp(18.3036-3816.44/(0+273-46.13))+.4←E
100: (U[1]-r1)/(S[1]-O[1])*(C[1]-O[1])+r1←G
101: (U[2]-r2)/(S[2]-O[2])*(C[2]-O[2])+r2←F
102: (B-A)*X+H←Y[1]
103: Y[1]/F←Y[2]
104: Y[2]*(310/(273+D))*((I[2]-E)/(I[2]+47))+Y[3]

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105: Y[3]*(273/310)*((I[2]-47)/760)+Y[4]
106: Y[4]*F+Y[5]
107: F*(1-r5)/(1-F)*r5-G)+R
108: Y[5]/R+Y[6]
109: fnt 5,/,f7.4,10x,f7.4;C+.5+L;wrt L,"FE O2=",G,"FE CO2=" ,F
110: fnt 5,2/,c7.4x,c7.6x,c1.9x,c3.9x,c4.6x,c4
111: wrt L,"VE BTP3","VE STPD","R","VO2","VCO2","TIME"
112: fnt 2,f7.3,4x,f7.3,4x,f5.2,3x,f7.3,6x,f7.3,5x,f6.2
113: C+.2+L;wrt L,Y[3],Y[4],R,Y[6],Y[5],K
114: fnt ,/,78"*",/,78"*"
115: wrt C;fnt
116: beep;wait 50;beep
117: dsp "RECAL.--Press f1 to continue"
118: if r14=1;0+r14;goto 120
119: goto 116
120: 0+r15
121: ent "Do you want to recal. O2 & CO2?",Q
122: if Q#1;fnt ;goto 67
123: dsp "Press CONF to recal. high O2,CO2";beep;fnt ;stp
124: cli 'SCAN'
125: fnt 7,78"+";C+.7+L
126: fnt ;wrt C;wrt L;wrt L
127: Z[1]+S[1];Z[2]+S[2]
128: wrt S,"New O2 high cal. read. = ",S[1]," volts"
129: wrt S,"New CO2 high cal. read. = ",S[2]," volts"
130: beep;beep;fnt
131: dsp "Press CONF to recal. low O2, CO2";beep;fnt ;stp
132: cli 'SCAN'
133: Z[1]+O[1];Z[2]+O[2]
134: wrt C
135: wrt S,"New O2 low cal. read. = ",O[1]," volts"
136: wrt S,"New CO2 low cal. read.= ",O[2]," volts"
137: wrt L;wrt L;fnt ;wrt C;beep;beep
138: fnt ,78"*",/,78"*",/,wrt C
139: fnt ;goto 67
140:

```

```

141: "SCAN":
142: 0→J;0→Z[1];0→Z[2];0→P
143: eir 9
144: oni 9,"TIME"
145: dsp "taking DVM readings"
146: wrt 9,"ULG/"
147: fmt 1,f3.0
148: wrt 709.1,1;trg 722;red 722,V[1];wrt 709.1,2;trg 722;red 722,V[2];J+1→J
149: V[1]+Z[1]→Z[1];V[2]+Z[2]→Z[2]
150: if P=1;jmo 2
151: gto 148
152: wrt 9,"U2V";red 9,K;K/60000→K
153: Z[1]/J→Z[1];Z[2]/J→Z[2];dsp
154: ret
155:
156: "TIME":
157: 1→P
158: iret

```

"manGAS"

Program Listing

```

0: "This program is called manGAS. It will calculate O2 consumption":
1: "and CO2 production when the appropriate experimentally measured values":
2: "are entered by hand.":
3: "Version: 16 March 1982 ** RPL ":
4:
5: dim B$[80],C$[20],D$[80],E$[80],F$[80],O[2],U[2],S[2],Z[2],I[2]
6: dim Y[6],A[2]
7: ldk 0
8: rew
9: dsp "Remove Program Tape";stp
10: ent "Enter Printer Select Code",D
11: if D=6;jmp 2
12: wtb 706,27,40,65
13: ent "Chamber Gauge Pressure (fsw)=?",C
14: ent "Surface Barometric Press (mm Hg)?",I[1]
15: 760*C/33.07+I[1]+I[2]
16: ent "Spirometer cal. constant (1/V)=?",X
17: ent "Syringe sample vol., liters?",H
18: ent "Inspired CO2 fraction=?",N
19: ent "Subject Name?",B$
20: fmt ;wrt D,"Subject name: ",B$
21: ent "Date?",C$
22: wrt D,"Date: ",C$
23: ent "Enter Heading, line 1 of 2",E$
24: 0+r3
25: ent "Enter Heading, line 2 of 2",F$
26: wrt D;wrt D,E$;wrt D,F$;wrt D
27: fmt 6,78"*/;D+r20+Q;wrt r20
28: cll 'CAL'
29: ent "Enter 1 to recalibrate",Q
30: if Q=1;0+Q;cll 'RECAL'
31: r3+1+r3
32: ent "Spirometer initial reading,volts",A

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```

33: ent "Spirometer final reading,Volts",B
34: ent "Body temp. in degrees C=?",J
35: ent "Time duration of collection,min.",T
36: ent "Spirometer tempo. in deg. C",W
37: ent "O2 reading=?",Z[1]
38: ent "CO2 reading=?",Z[2]
39: fmt 2;/wrt D
40: fmt "O2 reading: ",f9.3," CO2 reading: ",f9.3
41: wrt D,Z[1],Z[2]
42: fmt "/,cl3,f2.0;wrt D,"Test Period #",r3
43: ent "Enter comment",D$;fmt ;wrt D,D$;fmt ;wrt D
44: fmt 4,f9.4,z
45: D+.4+r20;wrt r20,"Surface Barometric Pressure=",I[1]," mm Hg"
46: wrt r20,"Chamber Gauge Pressure=",C," fsw"
47: wrt r20,"Spirometer calibration constant=",X," liters/volt"
48: wrt r20,"Syringe volume=",H," liters"
49: wrt r20,"Inspired O2 conc.=" ,r5," "
50: wrt r20,"Spirometer initial reading=",A," Volts"
51: wrt r20,"Spirometer final reading=",B," Volts"
52: wrt r20,"Time duration of sample collection=",T," min."
53: wrt r20,"Spirometer temperature=",W," deg. C"
54: wrt r20,"Body temperature = ",J," deg. C"
55: ent "Change values?",Q
56: if Q=1;0+Q;goto 32
57: exp(18.3036-3816.44/(J+273-46.13))+.4+K
58: exp(18.3036-3816.44/(W+273-46.13))+.4+E
59: (U[1]-r1)/(S[1]-O[1])*(Z[1]-O[1])+r1+G
60: (U[2]-r2)/(S[2]-O[2])*(Z[2]-O[2])+r2+F
61: (D-A)*X+H+Y[1]
62: Y[1]/P+Y[2]
63: Y[2]*((273+J)/(273+W))*((I[2]-E)/(I[2]-K))+Y[3]
64: Y[3]*((273+J)/(273+W))*((I[2]-K)/(760))+Y[4]
65: Y[4]*F+Y[5]
66: F*(1-r5)/(1-F)*r5-G)+R
67: Y[5]/R+Y[6]
68: D+.5+r20

```

```

69: fnt 5,/ ,f7.4,l0x,f7.4;wrt r20,"FE O2= ",G,"FE CO2=",F'
70: fnt 5,2/,c7,4x,c7,6x,c1,9x,c3,9x,c4
71: wrt r20,"VE 8PPS","VC SFPD","R","VO2","VCO2"
72: fnt 2,f7.3,4x,f7.3,4x,f5.2,3x,f7.3,6x,f7.3
73: D+.2+;wrt r20,Y[3],Y[4],R,Y[6],Y[5]
74: fnt //,78"*"/,78"x"
75: wrt D
76: gto 29
77: "CAL":
78: fnt //,78"-";wrt D;int
79: ent "O2 low cal. fraction=?",r1
80: ent "O2 low cal. reading=?",O[1]
81: ent "CO2 low cal. fraction=?",r2
82: ent "CO2 low cal. reading=?",O[2]
83: fnt 9,c24,4x,"O2:",2x,f7.4,5x,"CO2:",2x,f7.4
84: D+.9+r20;wrt r20,"Low cal. gas voltages:",O[1],O[2]
85: fnt 1,"O2 low cal. conc.=" ,f7.4,2x,"CO2 low cal. conc.=" ,f7.4
86: fnt ;wrt D;D+.1+r20;wrt r20,r1,r2
87: ent "Change values?",Q
88: if Q=l;U+Q;gto 79
89: ent "O2 high cal. fraction=?",U[1]
90: ent "O2 high cal. reading=?",j[1]
91: ent "CO2 high cal. fraction=?".U[2]
92: ent "CO2 high cal. reading=?",j[2]
93: fnt ;wrt D;D+.9+r20
94: wrt r20,"High cal. gas voltages:",S[1],j[2]
95: fnt ;wrt D
96: fnt 2,"O2 high cal. conc. =",f7.4,2x,"CO2 high cal. conc.=" ,f7.4
97: D+.2+r20;wrt r20,U[1],U[2]
98: ent "Change values?",Q
99: if Q=l;U+Q;qto 89
100: fnt //,78"-";wrt D;fnt
101: ret
102: "RECAL":
103: fnt ;wrt D;wrt B," <<<<<<<<<<<<<<<<>>>>>>>>"
104: cll 'CAL'

```

105: ret
106: end

Appendix 5

IDENTIFICATION OF FILES ON PROGRAM TAPE

File #	Size	Program Name
0	100	(special function keys)
1	7000	"GAS1"
2	6000	"GAS2"
3	5000	"manGAS"